IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS
MIDLAND DIVISION

Finalrod IP, LLC and R2R and D, LLC d/b/a Superod,	§	
	§	CIVIL ACTION NO. 7:15-cv-00097
Plaintiffs,	§	
	§	JURY TRIAL DEMANDED
v.	§	
	§	
John Crane, Inc. and John Crane Production Solutions, Inc.,	§	
	§	
Defendants.	§	

PLAINTIFFS' ORIGINAL COMPLAINT

Plaintiffs, Finalrod IP, LLC ("Finalrod") and R2R and D, LLC, d/b/a Superod ("Superod," collectively "Plaintiffs"), bring this action against Defendants John Crane, Inc. ("JCI") and John Crane Production Solutions, Inc. ("JCPS," collectively "Defendants") and through this Original Complaint show the following:

I. THE PARTIES

1. Plaintiff, Finalrod IP, LLC, is a Texas limited liability company, having a place of business at 610 South Main Street, Big Spring, Texas 79720.

2. Plaintiff R2R and D, LLC d/b/a Superod is also a Texas limited liability company, having a place of business at 610 South Main Street, Big Spring, Texas 79720.

3. John Crane, Inc. is a Delaware corporation, headquartered at 6400 W. Oakton Street, Morton Grove, IL and which may be served with process through its registered agent, CT Corporation System at 1999 Bryan Street, Suite 900, Dallas, Texas 75201. JCI has a registered place of business in Texas at 4001 Fair Drive, Pasadena, Texas 77507. Upon information and belief, JCI is the parent company of and controls JCPS.

4. John Crane Production Solutions, Inc. has a regular and established place of business in this judicial district at 6308 West Interstate 20, Midland, Texas 79706. JCPS may be served with process through its registered agent, CT Corporation System at 1999 Bryan St., Suite 900, Dallas, TX 75201.

II. JURISDICTION AND VENUE

5. This action arises under the patent laws of the United States, Title 35, Section 1, *et. seq*. of the United States Code. This Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331 and 1338(a).

6. Furthermore, on information and belief, Defendants, either directly or through intermediaries, make, use, sell or offer to sell products in this judicial district that infringe the '162 patent, identified below.

7. Venue is proper in this district pursuant to 28 U.S.C. §§ 1391 and 1400(b).

PATENT INFRINGEMENT

8. Plaintiff, Finalrod, is the owner of United States Patent No. 8,851,162 ("the '162 patent"), titled "Sucker Rod Apparatus and Method." A true and correct copy of the '162 patent, which was duly and legally issued by the United States Patent and Trademark Office on October 7, 2014, is attached hereto as Exhibit A. Pursuant to 35 U.S.C. § 282, the '162 patent is presumed valid and enforceable.

9. Plaintiff Superod is the exclusive licensee of the '162 patent.

10. The '162 Patent relates generally to a novel design for a fiberglass sucker rod. A sucker rod is used to increase the efficacy of sub-surface pumps in instances where the pressure in an oil reservoir is not sufficient to lift the oil to the surface. Individual sucker rods are grouped together to form a rod string and the connection of successive rods has been the source of

continued developmental efforts in the industry. The '162 patent relates to a fiberglass rod with connectors on each end that is an improvement over prior designs and methods. Specifically, each connector has a rod-receiving receptacle with an open end, a closed end, and axially spaced annular wedge shaped surfaces such that the compressive forces between the rod and the respective connector are defined by the shape of the wedged surfaces.

11. Defendants and Superod are direct competitors in the fiberglass sucker rod market. On information and belief, Defendants have had knowledge of the claims of the '162 patent since February 14, 2013, the publication date of the application which became the '162 patent.

12. On information and belief, Defendants are and have been making, using, offering for sale and/or selling within the United States, products and/or methods that fall within the scope of one or more of the claims of the '162 patent. Specifically, Defendants have promoted, through a video presentation and white paper, their "standard design of an end fitting" that infringes one or more of the claims in the '162 patent. A true and correct copy of the Defendants' paper is attached hereto as Exhibit B. On information and belief, Defendants have been making, using, selling, and offering for sale products based upon the same content detailed in the paper and video.

13. Accordingly, on information and belief, Defendants are infringing the '162 patent and are thus liable for infringement pursuant to 35 U.S.C. § 271(a).

14. Defendants are liable to Plaintiffs for damages that are adequate to compensate for the infringement under 35 U.S.C. § 284, which shall in no event be less than a reasonable royalty.

15. Defendants' infringement is done with knowledge of the '162 patent and Plaintiffs' interests therein. Defendants' infringement has therefore been willful, entitling Plaintiffs to enhanced damages and attorneys' fees under 35 U.S.C. § 285.

16. Because Defendants' and Superod compete directly in the fiberglass sucker rod market, Defendants' infringement of the '162 patent has caused and will continue to cause irreparable damage to Superod's business, including but not limited to a loss of goodwill and reputation and a loss of market share and price erosion. There is no adequate remedy at law for Superod's irreparable damage, and it will continue unless Defendants' infringement is preliminarily and permanently enjoined by this Court.

JURY DEMAND

17. Pursuant to Rule 38 of the Federal Rules of Civil Procedure, Plaintiffs hereby demand a jury trial on all issues and claims so triable.

PRAYER FOR RELIEF

18. WHEREFORE, Plaintiffs prays for judgment and seek the following relief:

a) For judgment in Plaintiffs' favor that Defendants have infringed the '162 patent;

b) For a preliminary injunction enjoining the aforesaid acts of infringement by Defendants, their officers, agents, servants, employees, subsidiaries and attorneys, and those persons acting in concert with Defendants, including related individuals and entities, customers, representatives, OEMs, dealers, distributors and/or importers;

c) For a permanent injunction enjoining the aforesaid acts of infringement by Defendants, their officers, agents, servants, employees, subsidiaries and attorneys, and those persons acting in concert with Defendants, including related individuals and entities, customers, representatives, OEMs, dealers, distributors and/or importers;

d) For judgment and an order requiring Defendants to pay Plaintiffs' their damages, costs, expenses, pre-judgment interest, and post-judgment interest for Defendants' infringement of the '162 patent, as provided under 35 U.S.C. § 284

e) For judgment and an order that this case is exceptional under 35 U.S.C. § 285 and requiring Defendants to pay Plaintiffs' reasonable attorneys' fees; and

f) For such other and further relief as the Court may deem just and proper.

DATED: June 29, 2015

RESPECTFULLY SUBMITTED,

/s/Guy E. Matthews
Guy E. Matthews
TX Bar No. 13207000
MATTHEWS, LAWSON, MCCUTCHEON, & JOSEPH, PLLC
2000 Bering Drive, Suite 700
Houston, Texas 77057
TEL: (713) 355-4200
FAX: (713) 355-9689
gmatthews@matthewsfirm.com

and

A. Harper Estes
TX Bar No. 00000083
Lynch, Chappell & Alsup, P.C.
The Summit, Suite 700
300 North Marienfeld
Midland, Texas 79701
TEL: (432) 683-3351
FAX: (432) 683-2587

EXHIBIT A

US008851162B2

(12) **United States Patent**
Rutledge et al.

(10) **Patent No.: US 8,851,162 B2**
(45) **Date of Patent: Oct. 7, 2014**

(54) **SUCKER ROD APPARATUS AND METHOD**

(76) Inventors: **Russell P. Rutledge**, Big Spring, TX (US); **Russell P. Rutledge, Jr.**, Big Spring, TX (US); **Ryan B. Rutledge**, Big Spring, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 606 days.

(21) Appl. No.: **13/136,715**

(22) Filed: **Aug. 9, 2011**

(65) **Prior Publication Data**

US 2013/0039692 A1 Feb. 14, 2013

(51) **Int. Cl.**

E21B 43/00	(2006.01)
F16B 7/00	(2006.01)
F04B 53/14	(2006.01)
E21B 17/10	(2006.01)
F04B 47/02	(2006.01)
B29C 65/00	(2006.01)
B29C 65/54	(2006.01)
B29C 65/48	(2006.01)
B29L 31/06	(2006.01)

(52) **U.S. Cl.**

CPC ***F04B 53/14*** (2013.01); *B29C 66/5261* (2013.01); *B29C 65/542* (2013.01); ***E21B 17/1071*** (2013.01); *B29C 65/4835* (2013.01); *B29C 66/53* (2013.01); *B29L 2031/06* (2013.01); *B29C 66/721* (2013.01); ***F04B 47/02*** (2013.01); *B29C 66/1246* (2013.01); *B29C 66/12441* (2013.01)

USPC **166/68**; 166/105; 403/265; 403/268

(58) **Field of Classification Search**

USPC 166/68, 105; 403/268, 265

See application file for complete search history.

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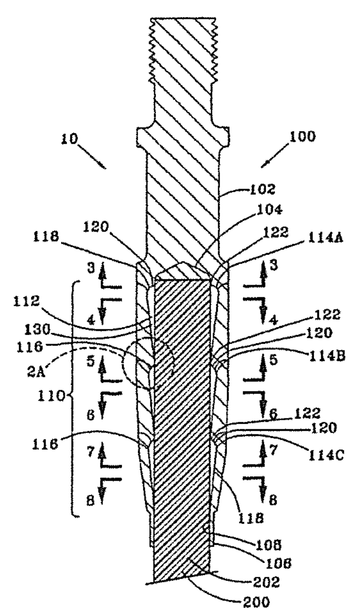
Primary Examiner — Giovanna Wright

(57) **ABSTRACT**

The present disclosure relates to a fiberglass rod with connectors on each end. Each connector has a rod-receiving receptacle having an open end, a closed end, and axially spaced annular wedge shaped surfaces such that the compressive forces between the rod and the respective connector are defined by the shape of the wedged surfaces.

40 Claims, 5 Drawing Sheets



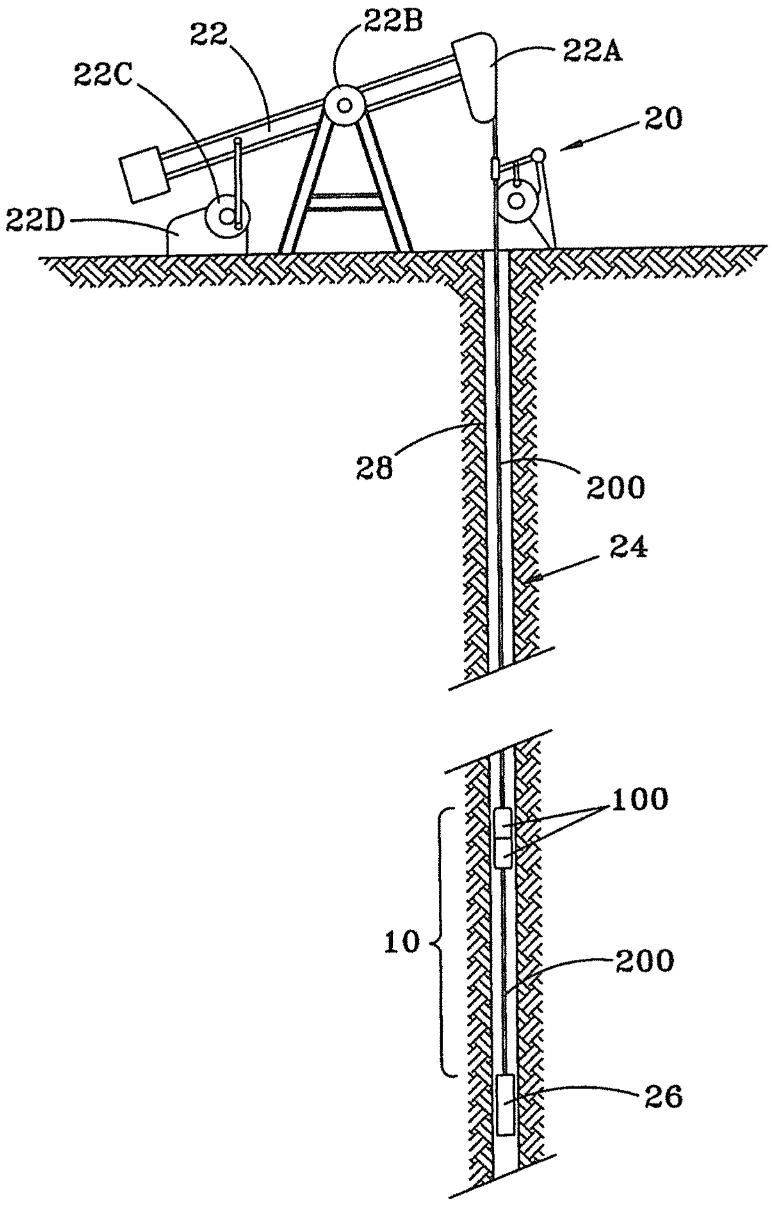
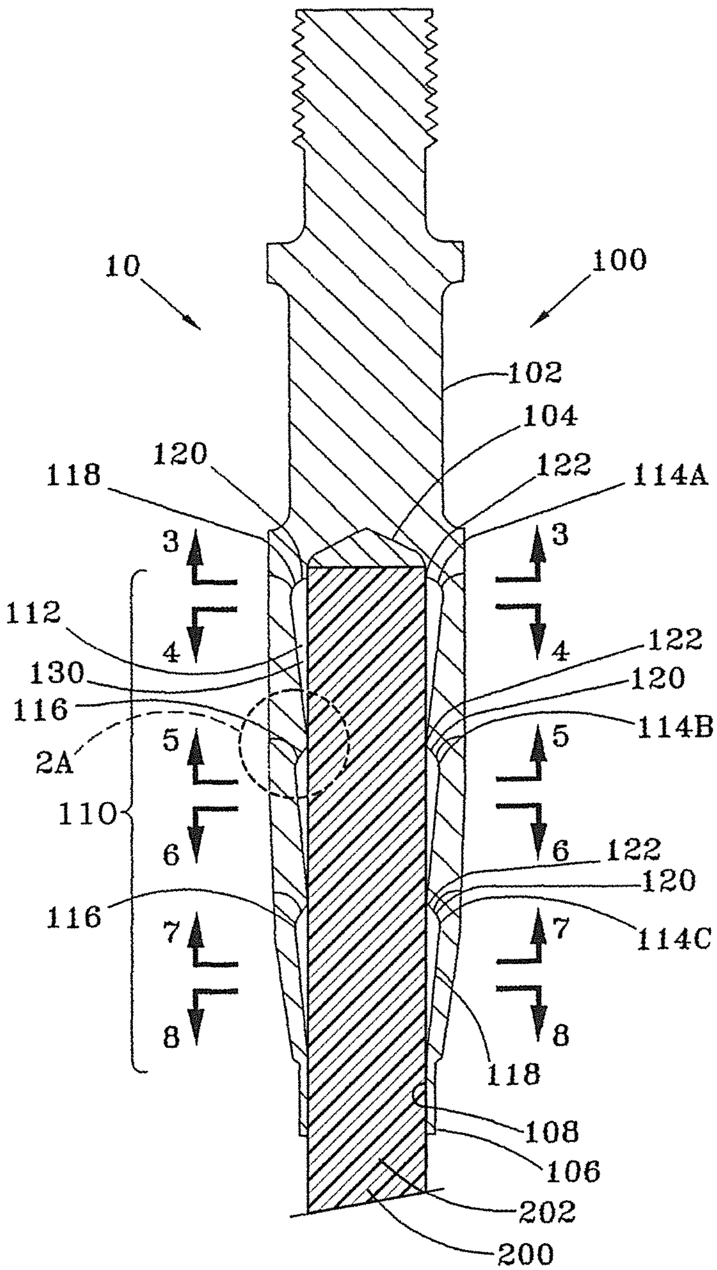


FIG. 1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100
102
104
118
120
122
114A
3
3
112
4
4
122
130
120
116
114B
5
5
2A
110
6
6
122
120
116
7
7
114C
8
8
118
108
106
202
200

FIG. 2

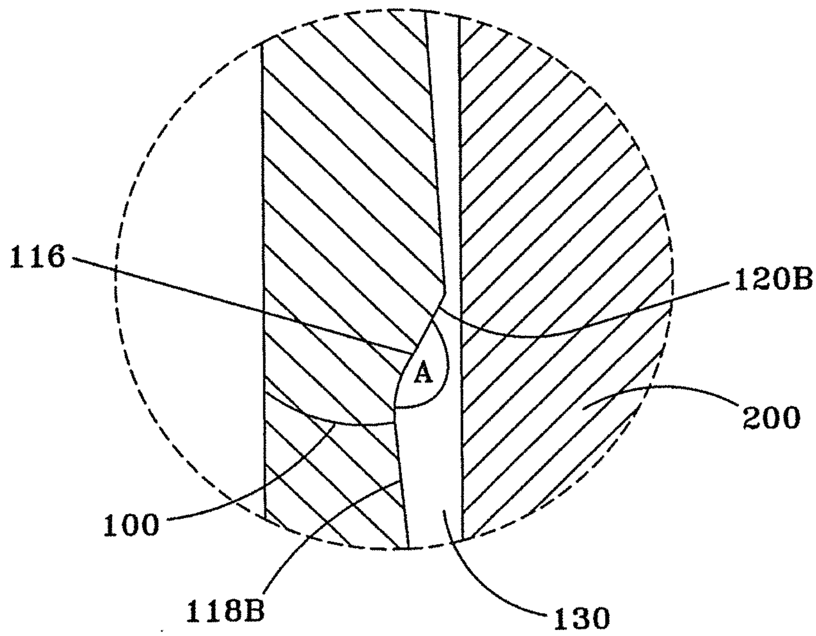
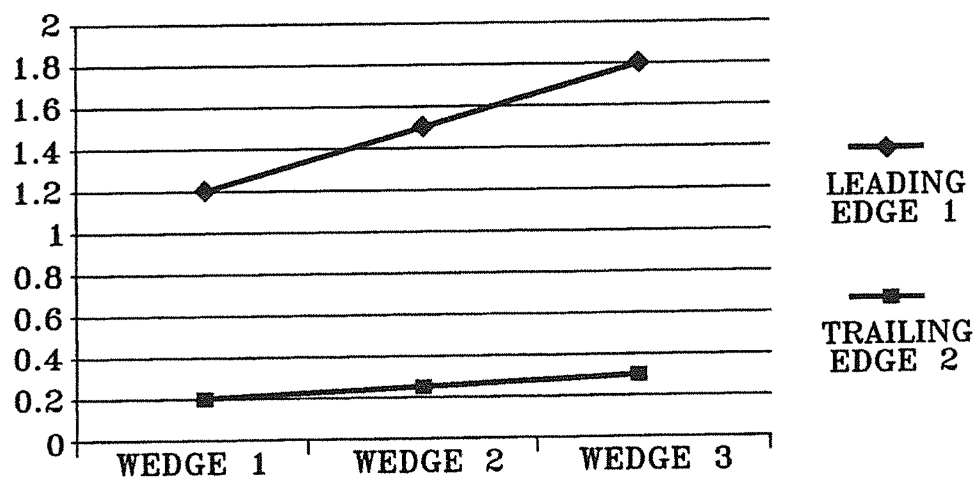

116
120B
A
200
100
118B
130

FIG.2A


2
1.8
1.6
1.4
1.2
1
0.8
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0.2
0
WEDGE 1
WEDGE 2
WEDGE 3
LEADING EDGE 1
TRAILING EDGE 2

FIG.9

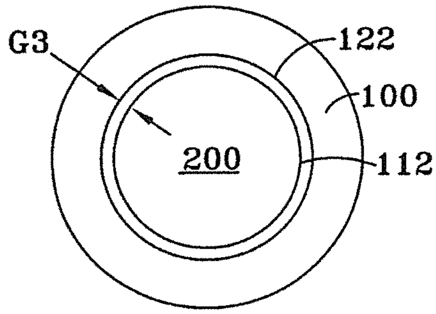

FIG.3

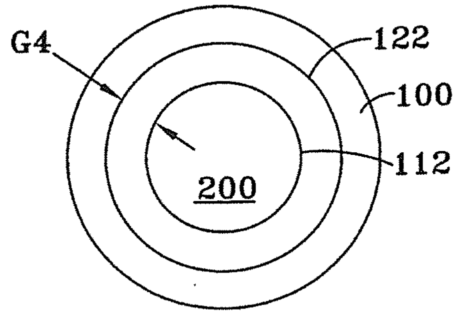

FIG.4

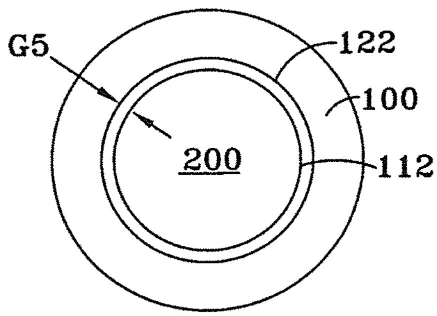

FIG.5

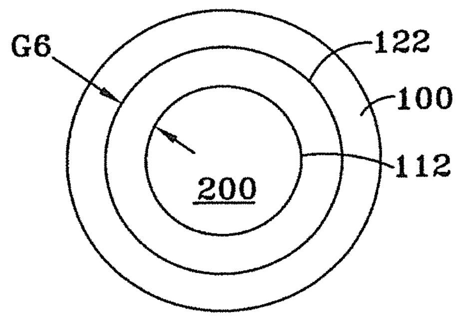

FIG.6

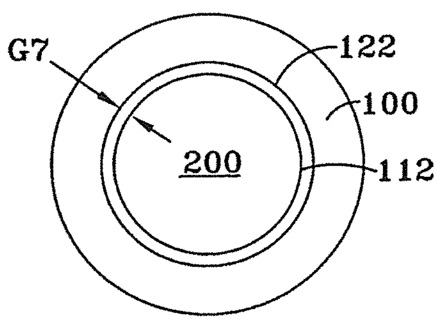

FIG.7

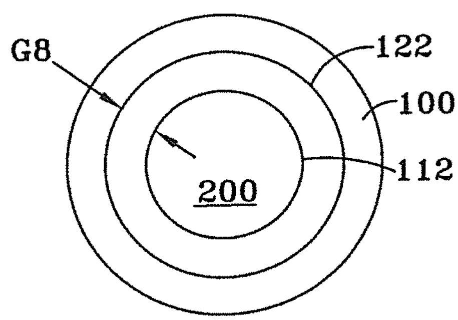

FIG.8

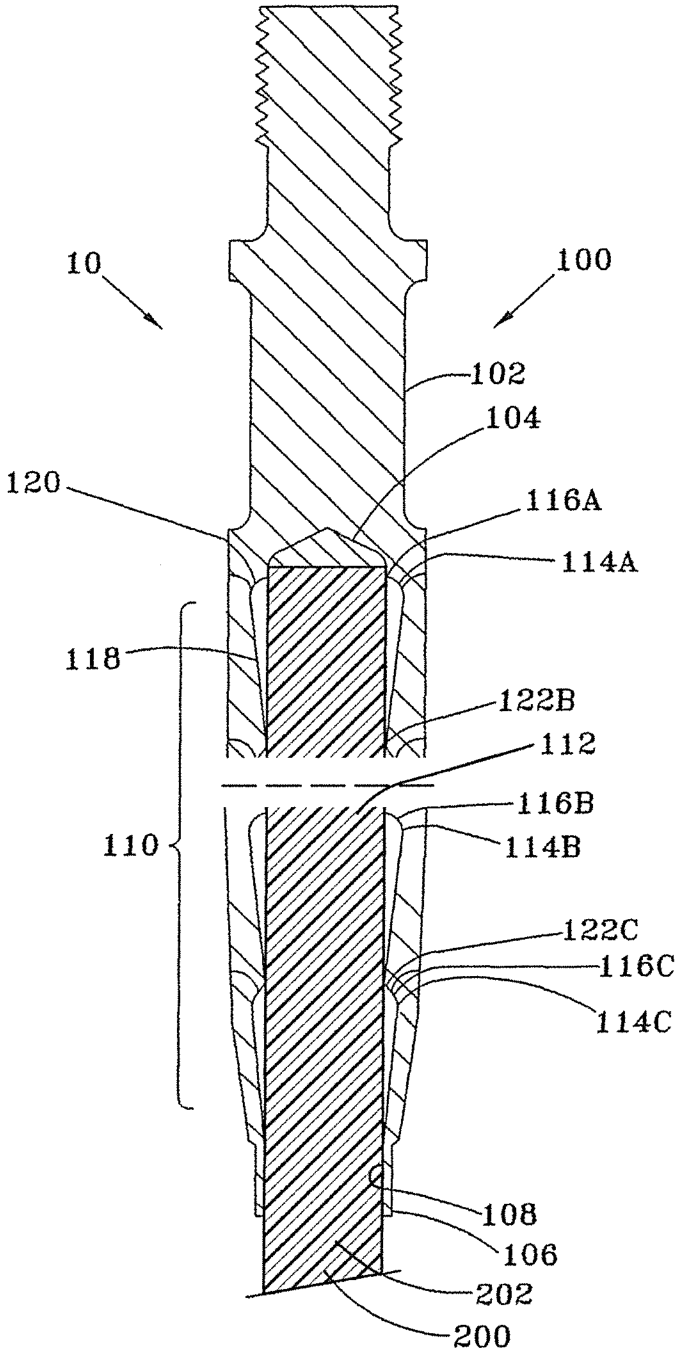
10
100
102
104
120
116A
114A
118
122B
112
116B
110
114B
122C
116C
114C
108
106
202
200

FIG. 10

SUCKER ROD APPARATUS AND METHOD

FIELD

The present disclosure relates generally to oil well sucker rods. In particular, the disclosure relates to oil well sucker rods made of fiberglass with connectors on each end and the manufacture thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the disclosure and together with the general description of the disclosure and the detailed description of the preferred embodiments given below, serve to explain the principles of the disclosure.

FIG. **1** illustrates a typical pumping system for use with the technology of the present disclosure.

FIG. **2** is a cross-sectional view of an embodiment of a sucker rod and an associated end fitting within the scope of the present disclosure.

FIG. **2**A is an exploded view of the angle A between the leading edge and the trailing edge of a wedged-shaped portion of the wedge system.

FIG. **3** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **3-3**.

FIG. **4** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **4-4**.

FIG. **5** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **5-5**.

FIG. **6** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **6-6**.

FIG. **7** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **1-7**.

FIG. **8** is a sectional view of the sucker rod and end fitting combination illustrated in FIG. **2** taken along the section line **8-8**.

FIG. **9** is a graph of the relationship between the length of the leading edge and trailing edge of each wedged-shaped portion in the wedge system of the present disclosure.

FIG. **10** is a cross-sectional view of another embodiment of a sucker rod and an associated end fitting within the scope of the present disclosure.

The depicted embodiments of the sucker rod and associated connectors are described below with reference to the listed Figures.

The above general description and the following detailed description are merely illustrative of the generic disclosure, and additional modes, advantages, and particulars of this disclosure will be readily suggested to those skilled in the art without departing from the spirit and scope of the disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In many oil wells, the pressure in the oil reservoir is not sufficient to lift the oil to the surface. In such cases, it is conventional to use a sub-surface pump to force the oil from the well. A pumping unit located at the surface drives the sub-surface pump. The pumping unit is connected to the sub-surface pump by a string of sucker rods. The pumping unit moves the sucker rod string up and down to drive the sub-surface pump.

Originally, a sucker rod was a special steel pumping rod. A sucker rod is, typically, a steel rod that is used to make up the mechanical assembly between the surface and the downhole components of a rod pumping system. Several sucker rods were screwed together to make up the mechanical link, or sucker rod string, from a beam-pumping unit on the surface to the subsurface pump at the bottom of a well. The sucker rods were threaded on each end and manufactured to dimension standards and metal specifications set by the petroleum industry. Typically, sucker rods have been in the lengths of 25 or 30 feet (7.6 or 9.1 meters), and the diameter varies from ½ to 1⅛ inches (12 to 30 millimeters).

Thus, sucker rod pumping is a method of artificial lift in which a subsurface pump located at or near the bottom of the well and connected to a string of sucker rods is used to lift the well fluid to the surface. The weight of the rod string and fluid is counterbalanced by weights attached to a reciprocating beam or to the crank member of a beam-pumping unit or by air pressure in a cylinder attached to the beam.

Due to the heavy weight of the steel sucker rods, large pumping units were required and pumping depths were limited. It is now preferable to use sucker rods made of fiberglass with steel connectors. The fiberglass sucker rods provide sufficient strength, and weigh substantially less than steel rods.

Since the development of the fiberglass sucker rod, there have been continued efforts to improve the sucker rod, and particularly, the relationship between the steel connectors and the successive rods.

FIG. **1** illustrates a generic pumping system **20**. The pumping system **20** includes a pump drive **22**, which is a conventional beam pump, or pump jack and is connected to a downhole pump **26** through a sucker rod string **24** inserted into wellbore **28**. The sucker rod string **24** can comprise a continuous sucker rod **10**, which extends from the downhole pump **26** to the pumping system **20**, a series of connected sucker rods **10**, a series of conventional length rods connected together, or any combination thereof. The pump drive **22** includes a horsehead **22**A, a beam **22**B, a gearbox **22***c* and a motor **22**D. Preferably, the sucker rod **10** is a fiberglass or composite rod. As described herein, the sucker rod string **24** may be the same as the continuous sucker rod **10** when the continuous sucker rod **10** is a one-piece rod that extends substantially between the pump drive **22** and the sub-surface pump **26**.

FIG. **2** is a cross-sectional view of an embodiment of the sucker rod **10** comprising a fiber composite rod **200** and associated end fitting **100** within the scope of the present disclosure. The sucker rod **10** comprises one or more end fittings **100** and the fiber composite rod **200**. The fiber composite rod **200** has a first end **202** and a second end (not illustrated).

Typically, there are end fittings **100** on each end of the fiber composite rod **200** for coupling together a plurality of fiber composite rods **200**. The end fitting **100** comprises an exterior surface **102**, a closed end **104**, an open end **106**, and an interior surface **108**. The interior surface **108** comprises a wedge system **110**. The present disclosure provides that the wedge system **110** can have any number of wedges with three wedges preferred. The wedge system **110** defines a cavity **112** in the end fitting **100**.

Further, the wedge system **110** comprises a plurality of wedged-shaped portions **114**. Each wedged-shaped portion **114** has an apex **116**, a leading edge **118** and a trailing edge

120 extending from the apex 116. Each apex 116 forms a perimeter 122 within the cavity 112 that is the narrowest part of the cavity 112 associated with each wedge shaped portion 114. The leading edge 118 is longer than the trailing edge 120 with the leading edge 118 facing the open end 106 and the trailing edge 120 facing the closed end 104 with respect to each wedge shaped portion 114.

The first wedge shaped portion 114A is proximate to the closed end 104 for receiving compressive forces that are greater than the compressive forces associated with the other wedged-shaped portion 114B, C. Particularly, the first wedged-shaped portion 114A receives greater compressive forces than the compressive forces for which a second wedge shaped portion 114B receives that is proximate to the first wedged-shaped portion 114. A third wedge shaped portion 114C between the second wedge shaped portions 114B and the open end 106 receives compressive forces that are less than the compressive forces associated with the first and second wedge shaped portions 114A, 114C. Therefore, the compressive forces create a force differential along each wedge shaped portion 114 greater at the closed end 104 of the end fitting 100 and decreasing toward the open end 106 of the end fitting 100.

As the compressive forces associated with the first wedged-shaped portion 114A deteriorate the structural integrity of the first wedged-shaped portion 114A, then, it has been found that the uncompensated for compressive forces of the first wedged-shaped portion 114A are transferred to and accepted by the second wedged-shaped portion 114B. Similarly, as the compressive forces associated with the second wedged-shaped portion 114B deteriorate the structural integrity of the second wedged-shaped portion 114B, then it has been found that the uncompensated for compressive forces of the second wedged-shaped portion 114B are transferred to and accepted by the third wedged-shaped portion 114C.

Thus, a force transfer continuum is created by the wedge system 110. The force transfer continuum provides for a constant effectiveness between the end fitting 100 and the fiber composite rod 200 as the wedge system 110 deteriorates from one wedged-shaped portion 114 to the next wedged-shaped portion 114 of the wedge system 110.

The sucker rod 10 has a plurality of longitudinal cross-sections of the wedged-shaped portions 114, which forms a plurality of frustro-conical shapes within the cavity 112.

The wedge shaped portions 114 of the sucker rod 10 create different compressive forces on each respective edge 118, 120 thereof with the compressive force being approximately proportional to a length of each edge 118, 120. In one embodiment, the compressive force on each edge 118, 120 is directly proportional to the length of each edge 118, 120. Further, the plurality of wedge shaped portions 114 are determined by the angle associated between the leading edge 118 and the trailing edge 120.

An adhesive or epoxy 130 is used to sufficiently bond with the fiber composite rod 200 and engage with the end fitting 100. It is appreciated that any adhesive substance that will sufficiently bond with the fiber composite rod 200 and engage with the end fitting 100 may be used. The adhesive or epoxy 130 is placed in the cavity 112 and cured to bond with the fiber composite rod 200 in the cavity 112 for fixedly securing the end fitting 100 with the fiber composite rod 200.

In one embodiment, the angle A between the leading edge 118 and the trailing edge 120 of each wedge shaped portion is obtuse. FIG. 2 illustrates an angle A associated with each wedged-shaped portion 114 of the wedge system 110.

FIG. 2A is an exploded view of the angle A of the second wedged-shaped portion 114B of the wedge system 110. The fiber composite rod 200 is illustrated in the end fitting 100. The end fitting 100 defines the leading edge 118B and the trailing edge 120B to form the cavity 112. The angle between the leading edge 118B and the trailing edge 120B defines the angle A. Generally, the leading edge 118, the trailing edge 120 and the fiber composite rod 200 form a scalene triangle with the longest side of the scalene triangle being along the fiber composite rod 200, the shortest side of the scalene triangle being along the trailing edge 120, and the intermediate side of the scalene triangle being along the leading edge 118.

FIG. 3 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 3-3. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G3.

FIG. 4 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 4-4. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G4. The gaps G3 and G4 are associated with the first wedged-shaped portion 114A of the wedge system 110.

FIG. 5 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 5-5. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G5.

FIG. 6 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 6-6. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G6. The gaps G5 and G6 are associated with the second wedged-shaped portion 114B of the wedge system 110.

FIG. 7 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 7-7. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G7.

FIG. 8 is a sectional view of the fiber composite rod 200 and end fitting 100 combination illustrated in FIG. 2 taken along the section line 8-8. The end fitting 100 is exterior of the fiber composite rod 200 with the cavity 112 there between. The cavity 112 between the fiber composite rod 200 and the end fitting 100 forms a gap G8. The gaps G7 and G8 are associated with the second wedged-shaped portion 114C of the wedge system 110.

The smaller gaps G3, G5, G7 associated with each wedged-shaped portion 114 are substantially constant having essentially the same dimension. Similarly, the larger gaps G4, G6, G8 associated with each wedged-shaped portion 114 are substantially constant having essentially the same dimension. The symmetry provided by the relationship of the minimum gaps G3, G5, G7 and the maximum gaps G4, G6, G8 provides unforeseen results. Particularly, the symmetry provided by the relationship of the minimum gaps G3, G5, G7 and the maximum gaps G4, G6, G8 greatly enhances the stability and ability of the fiber composite rod 200 and end fitting 100 combination to accept enhanced compressive and back pressure forces associated with the reciprocating environment in which the sucker rods 10 are used.

FIG. 9 is a graph of the relationship between the length of the leading edge 118 and trailing edge 120 of each wedged-shaped portion 114 in the wedge system 110 of the present disclosure. As illustrated in FIG. 2, the leading edge 118 is progressively longer from the closed end 104 of the end fitting 100 to the open end 106 of the end fitting 100. Similarly, the trailing edge 120 is progressively longer from the closed end 104 of the end fitting 100 to the open end 106 of the end fitting 100. The functions defined by these relationships are illustrated in FIG. 9. Particularly, a line having a slope or gradient defines the function associated with the trailing edge 120, and a line having a slope or gradient defines the function associated with the leading edge 118.

The relationship of the function associated with the trailing edge 120 and the function associated with the leading edge 118 provides insight to the unforeseen effectiveness of the wedge system 110 of the present disclosure. It has been found that the rate of increase of the length of the leading edge 118 with respect to the rate of increase of the length of the trailing edge 120, as defined by the slope or gradient of each associated function, provides an enhanced sucker rod 10 and sucker rod system. The slope of the leading edge 118 associated with the wedge system 110 of the present disclosure is greater than the slope of the trailing edge 120 associated with the wedge system 110 of the present disclosure.

The wedge system 110 of the present disclosure as applied to a sucker rod 10 provides unforeseen effectiveness not before appreciated. The combination of the wedged-shaped portions 114, the relationship of the leading edge 118 to the trailing edge 120, the symmetry of the minimum gaps G3, G5, G7 and the maximum gaps G4, G6, G8 result in a wedge system 110 that provides improved and unpredicted functionality. Particularly, the improved and unpredicted functionality of the sucker rod 10 having the wedge system 110 of the present disclosure greatly enhances the stability of the sucker rod 10 and ability of the fiber composite rod 200 and end fitting 100 combination to accept enhanced compressive and back pressure forces associated with the reciprocating environment in which the sucker rods 10 are used.

FIG. 10 is a cross-sectional view of another embodiment of a sucker rod 50 and associated end fitting 100 within the scope of the present disclosure. The sucker rod 50 comprises one or more end fittings 100 and a fiber composite rod 200. The fiber composite rod 200 has a first end 202 and a second end (not illustrated).

Typically, there are end fittings 100 on each end of the fiber composite rod 200 for coupling together a plurality of fiber composite rods 200. The end fitting 100 comprises an exterior surface 102, a closed end 104, an open end 106, and an interior surface 108. The interior surface 108 comprises a wedge system 110. The present disclosure provides that the wedge system 110 can have any number of wedges as indicated by the broken line between the first wedged-shaped portion 114A and the second wedged-shaped portion 114B. The wedge system 110 defines a cavity 112 in the end fitting 100.

The wedge system 110 comprises a plurality of wedged-shaped portions 114. Each wedged-shaped portion 114 has an apex 116, a leading edge 118 and a trailing edge 120 extending from the apex 116. Each apex 116 forms a perimeter 122 within the cavity 112 that is the narrowest part of the cavity 112 associated with each wedge shaped portion 114. The leading edge 118 is longer than the trailing edge 120 with the leading edge 118 facing the open end 106 and the trailing edge 120 facing the closed end 104 with respect to each wedge shaped portion 114.

The first wedge shaped portion 114A is proximate to the closed end 104 for receiving compressive forces that are greater than the compressive forces associated with the other wedged-shaped portions 114B, C, etc. Particularly, the first wedged-shaped portion 114A receives greater compressive forces than the compressive forces for which a second wedge shaped portion 114B receives that is proximate to the first wedged-shaped portion 114A. A third wedge shaped portion 114C between the second wedge shaped portions 114B and the open end 106 receives compressive forces that are less than the compressive forces associated with the first and second wedge shaped portions 114A, 114C. Therefore, the compressive forces create a force differential along each wedge shaped portion 114 greater at the closed end 104 of the end fitting 100 and decreasing toward the open end 106 of the end fitting 100.

As the compressive forces associated with the first wedged-shaped portion 114A deteriorate the structural integrity of the first wedged-shaped portion 114A, then it has been found that the uncompensated for compressive forces of the first wedged-shaped portion 114A are transferred to and accepted by the second wedged-shaped portion 114B. Similarly, as the compressive forces associated with the second wedged-shaped portion 114B deteriorate the structural integrity of the second wedged-shaped portion 114B, then it has been found that the uncompensated for compressive forces of the second wedged-shaped portion 114B are transferred to and accepted by the third wedged-shaped portion 114C.

Thus, a force transfer continuum is created by the wedge system 110 regardless of the number of wedged-shaped portions 114 comprise the wedge system 110. The force transfer continuum provides for a constant effectiveness between the end fitting 100 and the fiber composite rod 200 as the wedge system 110 deteriorates from one wedged-shaped portion 114 to the next wedged-shaped portion 114 of the wedge system 110.

The wedge shaped portions 114 of the sucker rod 50 create different compressive forces on each respective edge 118, 120 thereof with the compressive force being approximately proportional to a length of each edge 118, 120. In one embodiment, the compressive force on each edge 118, 120 is directly proportional to the length of each edge 118, 120. Further, the plurality of wedge shaped portions 114 are determined by the angle associated between the leading edge 118 and the trailing edge 120.

An adhesive or epoxy 130 is used to sufficiently bond with the fiber composite rod 200 and for engagement with the end fitting 100. It is appreciated that any adhesive substance that will sufficiently bond with the fiber composite rod 200 and engage with the end fitting 100 may be used. The adhesive or epoxy 130 is placed in the cavity 112 and cured to bond with the fiber composite rod 200 in the cavity 112 for fixedly securing the end fitting 100 with the fiber composite rod 200.

In one embodiment, the angle A between the leading edge 118 and the trailing edge 120 of each wedge shaped portion is obtuse. FIG. 2A illustrates an angle A associated with each wedged-shaped portion 114 of the wedge system 110 with respect to the present disclosure.

The longitudinal cross sections of the concaved portions 110 form frustro-conical shapes. The concaved portions 110 create different compressive forces on each respective surface thereof with the compressive force being approximately proportional to the length of each surface. The compressive force on each surface increases toward the closed end 104 and decreases toward the open end 106. The compressive force on each first surface 118 is proportional to the length of each

surface. The compressive force on each second surface **120** is proportional to the length of each second surface.

The plurality of concaved portions **110** are determined by the angle associated between the first surface **118** and the second surface **120** of each concaved surface **110**. The angle between the first surface **118** and the second surface **120** of each concaved surface **110** is obtuse. Further, each wedge shape portion **114** may have a length proportional to the compressive force applied to the wedge shape **114**. The wedge shape **114** has a length that increases from the closed end **104** to the open end **106** of the end fitting **100**. The wedge shaped portions **114** may have a length that decreases from the closed end **104** to the open end **106** of the end fitting **100**.

In yet another embodiment, a method for manufacturing a sucker rod is provided. The method comprises the steps of constructing an end fitting comprising an exterior surface, a closed end, an open end, and an interior surface. The interior surface comprises at least three wedge shaped portions defining a cavity. The wedge shaped portions have an apex and a first and second length extending from the apex. The apex forms a perimeter that is the narrowest part of the cavity associated with each wedge shaped portion such that the first length is longer than the second length with the first length facing the open end and the second length facing the closed end with respect to each wedge shaped portion. The method further comprises engaging an end of a fiber composite rod into the cavity of the end fitting for creating a void between the fiber composite rod and the wedge shaped portions of the end fitting. Thereafter, injecting an epoxy into the void to bond with the fiber composite rod and to fixedly engage the wedge shaped portions of the end fitting for securing the end fitting to the fiber composite rod. This arrangement causes the stress to increase the elastic limit without permanent alteration of the fiber composite rod and epoxy combination in the cavity of the end fitting.

Thus, a first wedge shaped portion proximate to the closed end receives compressive forces that are greater than the compressive forces for which a second wedge shaped portion proximate to the open end receives, and an intermediate wedge shaped portion between the first and second wedge shaped portions for receiving compressive forces that are intermediate of the first and second wedge shaped portions. Such that the compressive forces create a force differential along the wedge shaped portion greater at the closed end of the fitting and decreasing toward the open end of the fitting.

The method for manufacturing a sucker rod may further comprise the step of creating different compressive forces on each respective surface of the wedge shaped portions with the compressive force being approximately proportional to the length of each surface.

Further, the method for manufacturing a sucker rod may comprise the step of the compressive force on each surface increasing toward the closed end and decreasing toward the open end.

Still further, the method for manufacturing a sucker rod may comprise the compressive force on each first surface being proportional to the length of each surface.

Yet still further, the method for manufacturing a sucker rod may comprise the compressive force on each second surface being proportional to the length of each second surface.

The method for manufacturing a sucker rod may comprise the plurality of wedge shaped portions being determined by the angle associated between the first surface and the second surface of each concaved surface. The method for manufacturing a sucker rod may have the angle between the first surface and the second surface of each concaved surface being obtuse.

The method for manufacturing a sucker rod wherein each wedge shape has a length proportional to the compressive force applied to the wedge shape. The method for manufacturing a sucker rod wherein each wedge shape has a length that increases from the closed end to the open end of the end fitting. The method for manufacturing a sucker rod wherein each wedge shape has a length that decreases from the closed end to the open end of the end fitting.

The invention has been shown in only one of its embodiments. It should be apparent to those skilled in the art that the invention is not so limited, but is susceptible to various changes and modifications without departing from the spirit of the invention.

It is understood that the steps of the method described above or as claimed is not required to be performed in the order as disclosed. It is further understood that not all of the steps are necessary to carry out the claimed method and different embodiments of the method may not use all of the steps as disclosed above.

While the present disclosure has been described with emphasis on certain embodiments, it should be understood that within the scope of the appended claims, the present locating sub system and method could be practiced other than as specifically described herein. Thus, additional advantages and modification will readily occur to those skilled in the art. The disclosure in its broader aspects is therefore not limited to the specific details, representative apparatus, and the illustrative examples shown and described herein. Accordingly, the departures may be made from the details without departing from the spirit or scope of the disclosed general inventive concept.

What is claimed is:

1. An end fitting for a sucker rod comprising:

an exterior surface, a closed end, an open end, and an interior surface,

the interior surface comprising a wedge system defining a cavity, wherein the wedge system comprises three wedge shaped portions having an apex, a leading edge and a trailing edge, each apex forming a perimeter of equal dimension within the cavity that is the narrowest part of the cavity associated with each wedge shaped portion such that the leading edge is longer than the trailing edge with the leading edge facing the open end and the trailing edge facing the closed end with respect to each wedge shaped portion,

wherein the leading edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a compression of the sucker rod in the end fitting, the trailing edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a back pressure associated with the sucker rod in the end fitting,

wherein the first wedge shaped portion is proximate to the closed end and receives compressive forces that are greater than the compressive forces which the second wedge shaped portion receives, and wherein the second wedge shaped portion receives compressive forces that are greater than the compressive forces which the third wedge shaped portion receives, such that the compressive forces create a force differential along the wedge system greater at the closed end of the fitting and decreasing toward the open end of the fitting.

2. The end fitting of claim **1**, wherein the wedge system creates different compressive forces on each respective wedge shaped portion thereof, with the compressive force being inversely proportional to a length of each edge.

3. The end fitting of claim 2, wherein the compressive force on each edge is inversely proportional to the length of each edge.

4. The end fitting of claim 1, wherein the wedge shaped portions are determined by an angle associated with the apex between the leading edge and the trailing edge.

5. The end fitting of claim 4, wherein the angle between the leading edge and the trailing edge of each concaved surface is obtuse.

6. The end fitting of claim 1, further comprising a fiber composite rod having an end engaged centrally within the end fitting.

7. The end fitting of claim 6, further comprising a second end fitting engaged with a second end of the fiber composite rod.

8. The end fitting of claim 6, further comprising an epoxy placed in the cavity for bonding with the fiber composite rod in the cavity for fixedly securing the end fitting with the fiber composite rod.

9. The end fitting of claim 8, wherein the epoxy is uniform in thickness between the wedge shaped portions and the fiber composite rod such that the maximum thickness is substantially constant and the minimum thickness is substantially constant.

10. The end fitting of claim 6, further comprising a beveled recess in the closed end for accepting and centrally aligning the fiber composite rod within the end fitting.

11. A sucker rod comprising:

a fiber composite rod having a first end and a second end; and

end fittings on each end of the fiber composite rod for coupling together a plurality of fiber composite rods, the end fitting comprising:

an exterior surface, a closed end, an open end, and an interior surface,

the interior surface comprising a wedge system defining a cavity, wherein the wedge system comprises three wedge shaped portions having an apex, a leading edge and a trailing edge, each apex forming a perimeter of equal dimension within the cavity that is a narrowest part of the cavity associated with each wedge shaped portion, such that the leading edge is longer than the trailing edge with the leading edge facing the open end and the trailing edge facing the closed end with respect to each wedge shaped portion,

wherein the leading edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a compression of the sucker rod in the end fitting, the trailing edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a back pressure associated with the sucker rod in the end fitting,

wherein the first wedge shaped portion is proximate to the closed end and receives compressive forces that are greater than the compressive forces which the second wedge shaped portion receives, and wherein the second wedge shaped portion receives compressive forces that are greater than the compressive forces which the third wedge shaped portion receives, such that the compressive forces create a force differential along the wedge system greater at the closed end of the fitting and decreasing toward the open end of the fitting.

12. The sucker rod of claim 11, wherein the wedge system creates different compressive forces on each respective

wedge shaped portion thereof with the compressive force being inversely proportional to a length of each edge.

13. The sucker rod of claim 12, wherein the compressive force on each edge is inversely proportional to the length of each edge.

14. The sucker rod of claim 11, wherein the wedge shaped portions are determined by an angle associated with the apex between the leading edge and the trailing edge.

15. The sucker rod of claim 14, wherein the angle between the leading edge and the trailing edge of each concaved surface is obtuse.

16. The sucker rod of claim 11, further comprising the fiber composite rod having each end engaged centrally within the end fitting.

17. The sucker rod of claim 16, further comprising an epoxy placed in the cavity for bonding with the fiber composite rod in the cavity for fixedly securing the end fitting with the fiber composite rod.

18. The sucker rod of claim 17, wherein the epoxy is uniform in thickness between the wedge shaped portions and the fiber composite rod such that the maximum thickness is substantially constant and the minimum thickness is substantially constant.

19. The sucker rod of claim 16, further comprising a beveled recess in the closed end for accepting and centrally aligning the fiber composite rod within the end fitting.

20. A sucker rod comprising:

a fiber composite rod having a first end and a second end; and

end fittings on each end of the fiber composite rod for coupling together a plurality of fiber composite rods, the end fitting comprising:

an exterior surface, a closed end, an open end, and an interior surface,

wherein the interior surface comprises a wedge system defining a cavity wherein the wedge system comprises an interior wedge shaped portion, at least one intermediate wedge shaped portion and an exterior wedge shaped portion, each wedge shaped portion having an apex, a leading edge and a trailing edge, each apex forming a perimeter of equal dimension within the cavity that is a narrowest part of the cavity associated with each wedge shaped portion, such that the leading edge is longer than the trailing edge with the leading edge facing the open end and the trailing edge facing the closed end with respect to each wedge shaped portion,

wherein each leading edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a compression of the sucker rod in the end fitting, each trailing edge is shorter at the closed end and increases progressively from the closed end to the open end thereby compensating for a back pressure associated with the sucker rod in the end fitting,

wherein the interior wedge shaped portion is proximate to the closed end and receives compressive forces that are greater than the compressive forces which the intermediate wedge shaped portion receives, and wherein the intermediate wedge shaped portion receives compressive forces that are greater than the compressive forces for which the exterior wedge shaped portion receives, such that the compressive forces create a force differential along the wedge system greater at the closed end of the fitting and decreasing toward the open end of the fitting.

21. The sucker rod of claim 20, wherein the wedge system creates different compressive forces on each respective wedge shaped portion thereof with the compressive force being inversely proportional to a length of each edge.

22. The sucker rod of claim 21, wherein the compressive force on each edge is inversely proportional to the length of each edge.

23. The sucker rod of claim 20, wherein the wedge shaped portions are determined by an angle associated with the apex between the leading edge and the trailing edge.

24. The sucker rod of claim 23, wherein the angle between the leading edge and the trailing edge of each concaved surface is obtuse.

25. The sucker rod of claim 20, further comprising the fiber composite rod having each end engaged centrally within the end fitting.

26. The sucker rod of claim 25, further comprising an epoxy placed in the cavity for bonding with the fiber composite rod in the cavity for fixedly securing the end fitting with the fiber composite rod.

27. The sucker rod of claim 26, wherein the epoxy is uniform in thickness between the wedge shaped portions and the fiber composite rod such that the maximum thickness is substantially constant and the minimum thickness is substantially constant.

28. The sucker rod of claim 25, further comprising a beveled recess in the closed end for accepting and centrally aligning the fiber composite rod within the end fitting.

29. The sucker rod of claim 20, further comprising

a ratio of the trailing edge to the leading edge of the interior wedge shaped portion that is larger than a ratio of the trailing edge to the leading edge of each subsequent adjacent trailing edge to leading edge ratio.

30. The sucker rod of claim 20, further comprising the ratio of the trailing edge to the leading edge of the interior wedge shaped portion is smaller than the ratio of the trailing edge to the leading edge of each subsequent adjacent trailing edge to leading edge ratio.

31. A method for manufacturing a sucker rod comprising the steps of:

constructing an end fitting comprising an exterior surface, a closed end, an open end, and an interior surface, the interior surface comprising a wedge system defining a cavity wherein the wedge system comprises an interior wedge shaped portion, at least one intermediate wedge shaped portion and an exterior wedge shaped portion, wherein each wedge shaped portion comprises an apex, a leading edge and a trailing edge, wherein each apex forms a perimeter of equal dimension within the cavity that is a narrowest part of the cavity associated with each wedge shaped portion such that the leading edge is longer than the trailing edge with the leading edge facing the open end and the trailing edge facing the closed end with respect to each wedge shaped portion;

engaging an end of a fiber composite rod into the cavity of the end fitting for creating a symmetrical void between the fiber composite rod and the wedge shaped portions of the end fitting, whereby the symmetrical void has symmetry along the longitudinal axis of the fiber composite rod;

injecting an epoxy into the symmetrical void to bond with the fiber composite rod and to fixedly engage the wedge shaped portions of the wedge system of the end fitting for securing the end fitting to the fiber composite rod such that as the epoxy is uniform in thickness between the wedge shaped portions and the fiber composite rod, and whereby the maximum thickness is substantially constant and the minimum thickness is substantially constant,

wherein the interior wedge shaped portion is proximate to the closed end and receives compressive forces that are greater than the compressive forces which the intermediate wedge shaped portion receives, and wherein the intermediate wedge shaped portion receives compressive forces that are greater than the compressive forces which the exterior wedge shaped portion receives, such that the compressive forces create a force differential along the wedge system greater at the closed end of the fitting and decreasing toward the open end of the fitting.

32. The method for manufacturing a sucker rod of claim 31, further comprising the step of creating different compressive forces on each respective surface of the wedge shaped portions with the compressive force being proportional to the length of each edge.

33. The method for manufacturing a sucker rod of claim 32, further comprising the step of the compressive force on each surface increasing toward the closed end and decreasing toward the open end.

34. The method for manufacturing a sucker rod of claim 31, wherein the compressive force on each leading edge is inversely proportional to the length of each leading edge.

35. The method for manufacturing a sucker rod of claim 31, wherein the compressive force on each trailing edge is inversely proportional to the length of each trailing edge.

36. The method for manufacturing a sucker rod of claim 31, wherein the plurality of wedge shaped portions are determined by the angle associated between a first surface and a second surface of each concaved surface.

37. The method for manufacturing a sucker rod of claim 36, wherein the angle between the first surface and the second surface of each concaved surface is obtuse.

38. The method for manufacturing a sucker rod of claim 31, wherein each wedge shaped portion has a length inversely proportional to the compressive force applied to the wedge shaped portion.

39. The method for manufacturing a sucker rod of claim 31, wherein each wedge shaped portion has a length that increases from the closed end to the open end of the end fitting.

40. The method for manufacturing a sucker rod of claim 31, wherein each wedge shaped portion has a length that decreases from the closed end to the open end of the end fitting.

* * * * *

EXHIBIT B

IT'S ALL ABOUT THE END FITTING: ADVANCED TESTING AND DESIGN IMPROVES FIBERGLASS SUCKER ROD

Ryan Gernentz, Karol Hricisak, Mohamed F. Alzoubi
John Crane

ABSTRACT

The full potential and benefits of the fiberglass sucker rods (FSR) are not being realized. FSR manufacturers are required to meet the requirements for increased operating ranges and one-time pull loads of FSR. Increasing the operating load requires the redesign of the end fitting to ensure reliability. This paper outlines the standard design of an end fitting and how it interfaces with the pulltruded fiberglass rod. Test data used to validate the design is also included. The overall wedge design is explained in detail, demonstrating the interaction of forces acting on the rod/end fitting interface. The stress range diagram will be presented with emphasis on the critical areas of the end fitting design. The overall goal is to show how the fiberglass rod combined with a new end fitting is stronger than high strength steel of equivalent pin size.

INTRODUCTION

Fiberglass Sucker Rods (FSR) have not been widely accepted, despite being able to increase production rates and reduce energy consumption. Two reasons for limited use is the limited strength of the rod as measured by average working load and maximum one-time pull and the mode of failure where rod breaks that are difficult to fish from the well.

This paper presents a unique design approach to the end fitting geometry and investigates how the strength of a fiberglass sucker rod performs as a system and how the load of a rod string can be distributed differently, addressing the two primary issues associated with the adoption and use of FSRs. Additionally, design changes and testing results are presented. Researchers and scientists around the globe, such as studies conducted by Woldesenbet, et al. [1], have investigated the effect of fatigue cycles on the performance of these sucker rods.

During the process of improving a FSR design, an understanding of how the product performs as a system helps to identify the limiting factors of current designs. Considering each component of the FSR, an evaluation of the glass strands, the resin used to hold the glass strands, the epoxy connecting the rod to the end fitting and the end fitting geometry was conducted. The overall strength of the assembly is based upon the components, but also on the interface and boundary conditions between the materials. The characteristics of these interfaces can contribute significant load carrying capability to the overall assembly. This paper discusses the fiberglass rod system, components of the system, including the rod body, end fitting and connection pin. Utilizing technology and data from laboratory testing results in an improved design, higher performance while improving and streamlining the overall design process.

FSR COMPONENTS AND MANUFACTURING PROCESS

A FSR consists of three integral components: a fiberglass rod, end fittings and epoxy between the two. A fiberglass rod body accounts for the majority of the size (length) of FSR. It consists of axially aligned glass strands bonded by resin. The glass strand material used in the John Crane FSR has a per-strand rating of 450-550 ksi in tension. The resin is used hold the glass strands together forming the rod body. A fiberglass rod is then capped with an end fitting at each end. An API pin is machined on the opposite side of the end fitting body to join another FSR via couplings. The end fitting is typically machined from metal bar stock with an internal cavity to accept the end of the fiberglass rod body and epoxy bonding agent. Per American Petroleum Institute (API) Specification 11B, the "C grade" steel alloy used in the end fittings has a limiting tensile rating of 90-115 ksi. The epoxy adheres to the rod body, not the end fitting, and serves as a means for transferring load from the end fitting wedges to the rod body.

As a part of the FSR assembly process, the internal cavity of the end fitting is filled with epoxy. It is then driven onto the end of the rod body. During this step, the epoxy fills all voids within the end fitting not occupied by the

fiberglass rod. The epoxy assumes the internal shape of the cavity and is then cured and hardened thru a heating and cooling process. Once cured and cooled a load is applied to the FSR in order to 'set the wedges'. As a final step required by API, the setting load is 110 percent of the maximum allowable working load in order to verify the quality of the assembly and minimize the effects of cyclic loading during normal operation.

END FITTING

The overall geometry of the end fitting is prescribed by API specification with the exception the internal cavity. The geometry of the internal cavity is essential to the assembly and the primary contributor to the performance of the FSR. The purpose of the of the wedge is to provide an increase in diameter (upset) at the end of the fiberglass rod to prevent the end fitting from pulling off the rod body when the operating load of the rod string is applied. The epoxy used to form the wedge is intended to create a maximum adhesion with a fiberglass rod body. Adhesion is not desired between the end fitting and the epoxy as it causes premature epoxy failure due to shearing. The wedge transfers the axial loading of the rod string to a radial load (N1) to the body of the end fitting as seen in Figure 1. F1 and F2 are equal and opposite forces as a result of the relative friction coefficient between the metal wall of the end fitting and the epoxy.

The resulting load (N2) acts opposite to the radial load (N1) in a compressive direction onto the rod body, transversely with respect to the fiberglass strands. The amount and the direction of compressive load are directly dependent on the internal geometry (angles of the wedges) of the end fitting. As a function of the wedge angle, the shallow angle would result in the load causing swelling or splitting of the end fitting or splintering of the fiberglass rod. On the other hand, a large angle would result in the load shearing the epoxy or the epoxy-rod body bond. The objective of redesigning the end fitting is to improve the current design by modifying the internal geometry of the end fitting while employing already established materials that are currently in use for the following two reasons:

1. Material is well established and proven.
2. There is significant opportunity for performance improvement by managing the distribution of stress.

It was determined to optimize the current design by modifying the force generated by N_2 along epoxy-wedge distributing the stress in the rod more evenly and making the interface as strong as possible.

ESTABLISHING A BASELINE

The first step in developing an improved end fitting was to understand the performance of the current design. A simplified axisymmetric model using Finite Element Analysis (FEA) was utilized to assist in this process. The material properties of the three components that were used in building the FEA model were extracted from several literatures such as those used in Kumosa, et al. [2, 3]. The model demonstrates the internal deformation and loading mechanisms of the 'end fitting-epoxy-fiberglass rod' joint. Figure 2-Figure 4 show the model elements, element mesh density and the resultant Von-Mises stress respectively of the baseline model.

From the results of the baseline model shown in Figure 4, the load distribution as a function of the internal geometry is clearly identified. Taking into account the limitations of the FEA analysis, this model was to establish critical areas of design only. An iterative process combined with lab testing was employed to establish a valid simulation envelop due to model's high sensitivity to assumed boundary conditions, material properties, and friction coefficients. A number of models were evaluated and the results within the linear elastic region were compared with the results of the tensile tests of the fiberglass rod. Standardized material testing of the fiberglass and the epoxy aided to fine tune the material properties used in the simulation model. The FEA results are highly dependent to the relative friction coefficients utilized within the model, in particular the epoxy-end fitting interface. If the joint is assumed frictionless the model results in low absolute tensile strength, but it would replicate the swelling of the end fitting. However, increasing the friction coefficient near the upper tolerances would result in the epoxy shearing prematurely, resulting in a low axial force .The final friction coefficient selected best matched the radial deformation and relative axial displacement between the components seen in lab testing. With the FEA model closely matching the lab results the confidence in the predicted stress plots is established. The derived baseline model can further be considered in future design decisions relevant to the end fitting internal geometry.

VIRTUAL PROTOTYPING

From the established baseline, conceptual designs were developed and analyzed using FEA to compare performance while varying the following key parameters:

1. Length of engagement (length of rod penetrating the end fitting)
2. Angles of the wedges
3. Epoxy thickness
4. Outside Diameter (OD) profiles
5. Stress concentration factors
6. Wedge Type (straight vs. asymptotic vs. hybrid)

Figure 5 shows total reaction force percentage vs. relative deflection between rod body and end fitting for various epoxy thicknesses.

These preliminary results suggest that varying epoxy thickness has minimal effect on the one-time pull load capacity of the end fitting. However results in Figure 6 show that the assembly is highly sensitive to variations of the wedge angles. The variation in the wedge angle affected both the slope of the linear region of the system as well as the peak load.

The remaining parameters were plotted to establish how the system reacted to the variations. The parameters with the highest response were selected to optimize the end fitting design. The best performing candidates were prototyped to be validated by lab testing. Figure 7 shows the results of validating the coefficient of friction against the lab results.

LAB TESTING

The John Crane lab has the capability to test steel or fiberglass rods up to 40ft in length with loads not to exceed 225kips. This tensile testing rig can perform one time pull to failure loading as well as cycle testing. There is a secondary test rig dedicated for cycle testing to failure while in a heated oil bath. The maximum rating on the cycle tester is 70 kips with a maximum oil bath temperature of 350°F. The initial lab testing consisted of loading the FSR assemblies until they parted while recording the load, elongation of each test, end fitting deformation and the failure mode. Each FSR concept underwent a number of lab tests to establish a consistency in results. Once the first round of lab testing was complete, the best characteristics were determined and utilized to proceed to the next revision of modeling. The FEA boundary conditions were again validated against the lab test results to assure good correlation. This iterative method of combining the virtual testing with actual testing was imperative to ensure that the FEA modeling represented physical performance.

Upon completion of the initial test matrix the variation in design parameters showed a close correlation to the various failure modes (rod break, end fitting deformation, epoxy failure, etc.). The test results were compiled and ranked based on the criteria listed below.

1. Standard deviation of Peak Load (2 kips -15 kips)
2. Peak Load (Variance 58 kips)
3. Failure mode (Pin Failure, Rod Body Break, End Fitting Swelling / Splitting, Epoxy Shear)
    a. Repeatability
    b. Predictability

However a number of the tests showed high ultimate load values, low standard deviations and preferred failure mode. Those candidates underwent additional iterations before arriving at designs selected for cycle testing. Up to this point, all design parameters were evaluated only by one time pull to failure tests due to simplicity and repeatability of the testing. Cyclic testing was performed as a final validation method against expected field operating conditions.

FINAL DESIGN

The final end fitting design consists of a four wedges with varying wedge angles and graduating lengths. This internal geometry was optimized using all available engagement length of the cavity. While maximizing the effective length of the cavity (rod engagement length), high stress regions were minimized to allow for the lowest possible stress per unit load.

Design goals were successfully achieved with a use of this iterative design process. The final design of the end fitting achieves considerably higher working loads, one time pull to failure loads with a predictable failure mode. John Crane's published literature shows a working load that is at least 25 percent higher than all other currently available fiberglass rod alternatives. Also, an increased ability to remove stuck pumps was achieved by an increase in the one-time pull load capacity of 30 percent. The failure mode of the rod pulled in tension no longer causes deformation to occur at the end fitting allowing the rod end to separate. Instead, the entire end fitting and epoxy connection is strengthened such that the pin can be the engineered point of failure allowing for easier retrieval of parted rods stings. The final allowable stress range diagram is provided in Figure 9.

CONCLUSION

The John Crane team was able to meet the objectives set for the new generation of the end fitting by employing the accelerated/iterative design process. This design process consisted of FEA modeling supported by lab test data. Lab testing assisted in both model setup and final verification of the performance. During this effort, the design team was able to establish correlation between geometry parameters (wedge angle, engagement length, and epoxy thickness) and end fitting performance (working load, one-time pull load, failure mode). The final design has the following improvements:

1. Working load that is at least 25 percent greater than all other currently available fiberglass rod alternatives.
2. Increased ability to remove stuck pumps achieved by an increase in the one-time pull load capacity of 30 percent.
3. The failure mode was also changed from end fitting swelling to a controlled pin failure higher than the breaking load of most high strength steel rods.

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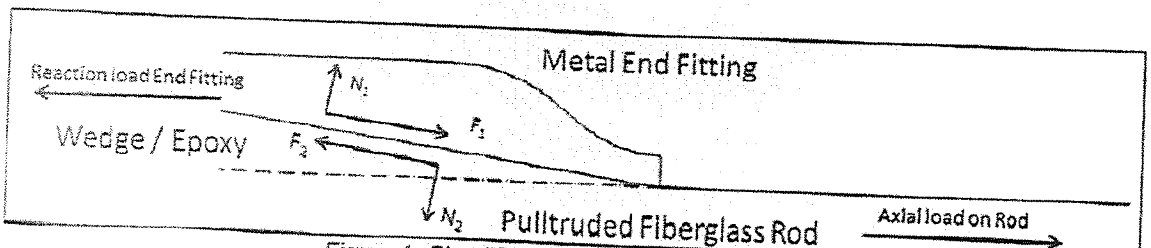


Figure 1- Simplified wedge free-body diagram

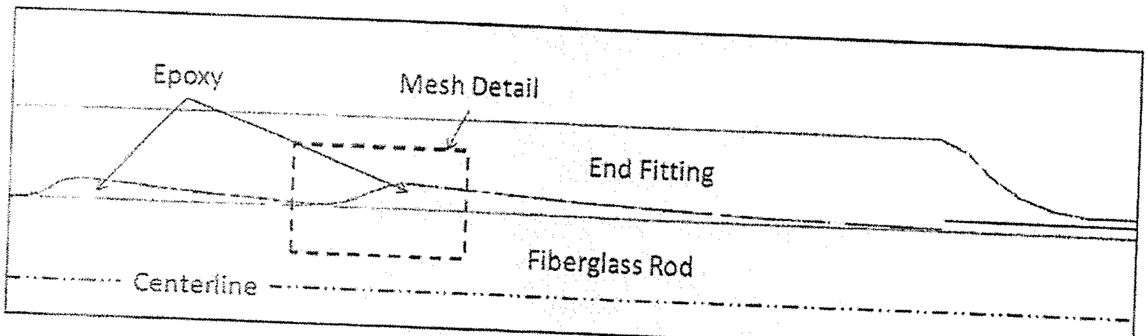


Figure 2- Baseline model of the axisymmetric sucker rod end fitting model used as a baseline

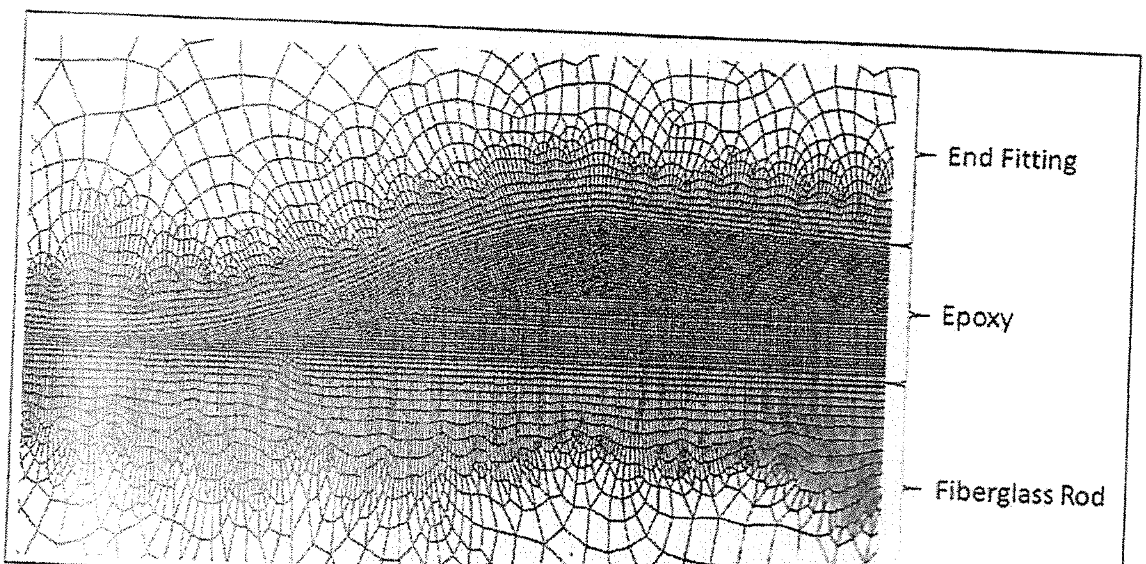


Figure 3- Mesh density detail of the baseline axisymmetric sucker rod end fitting model

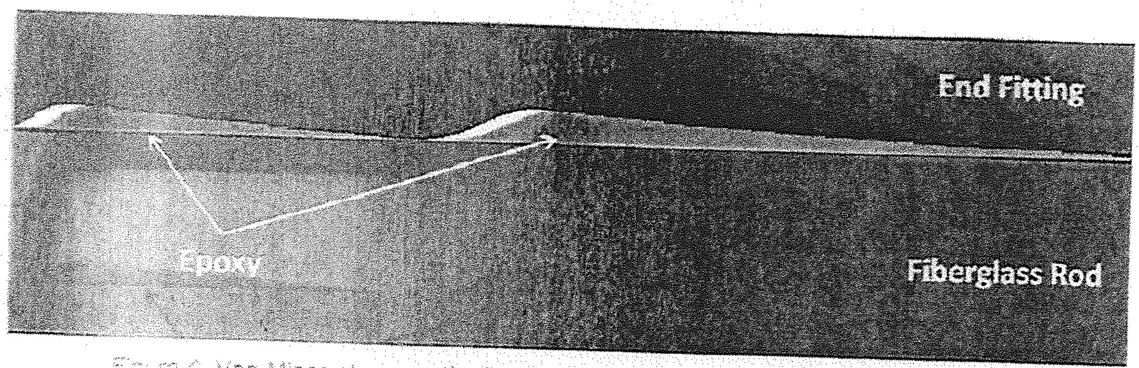


Figure 4- Von-Mises stress on the baseline axisymmetric sucker rod end fitting model

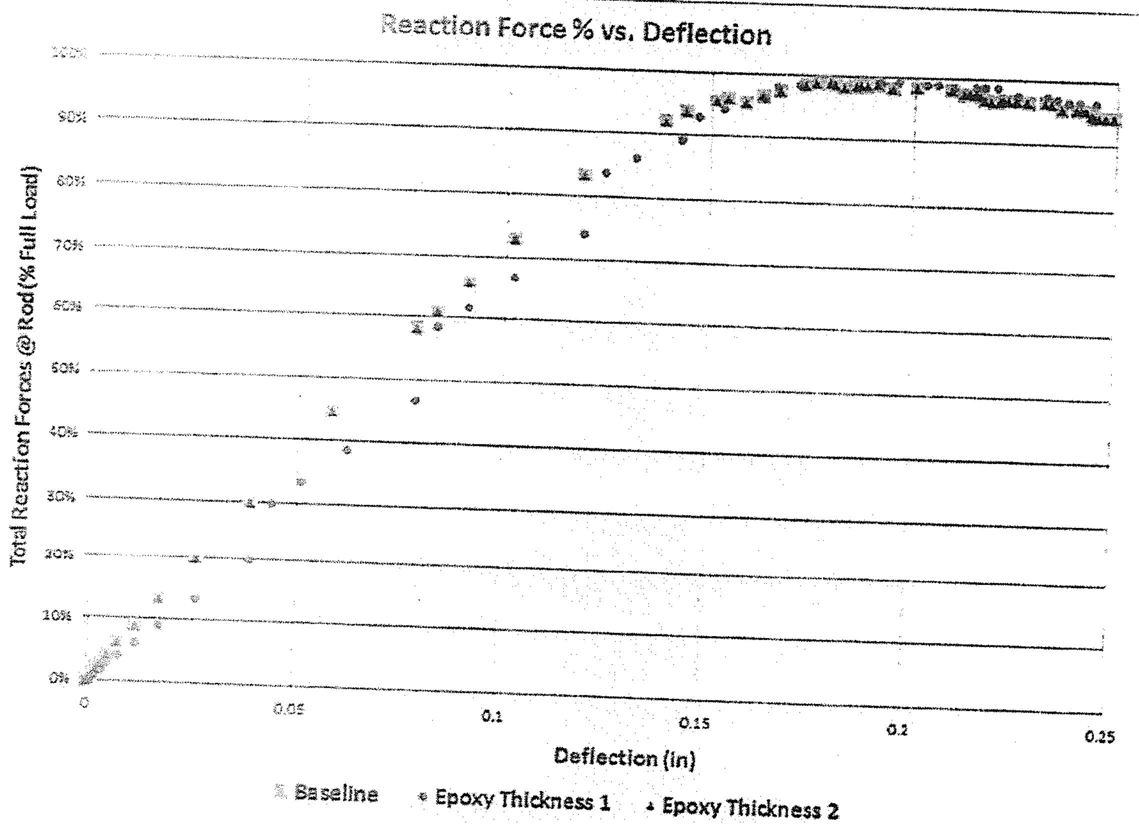


Figure 5- Results of varying epoxy thickness

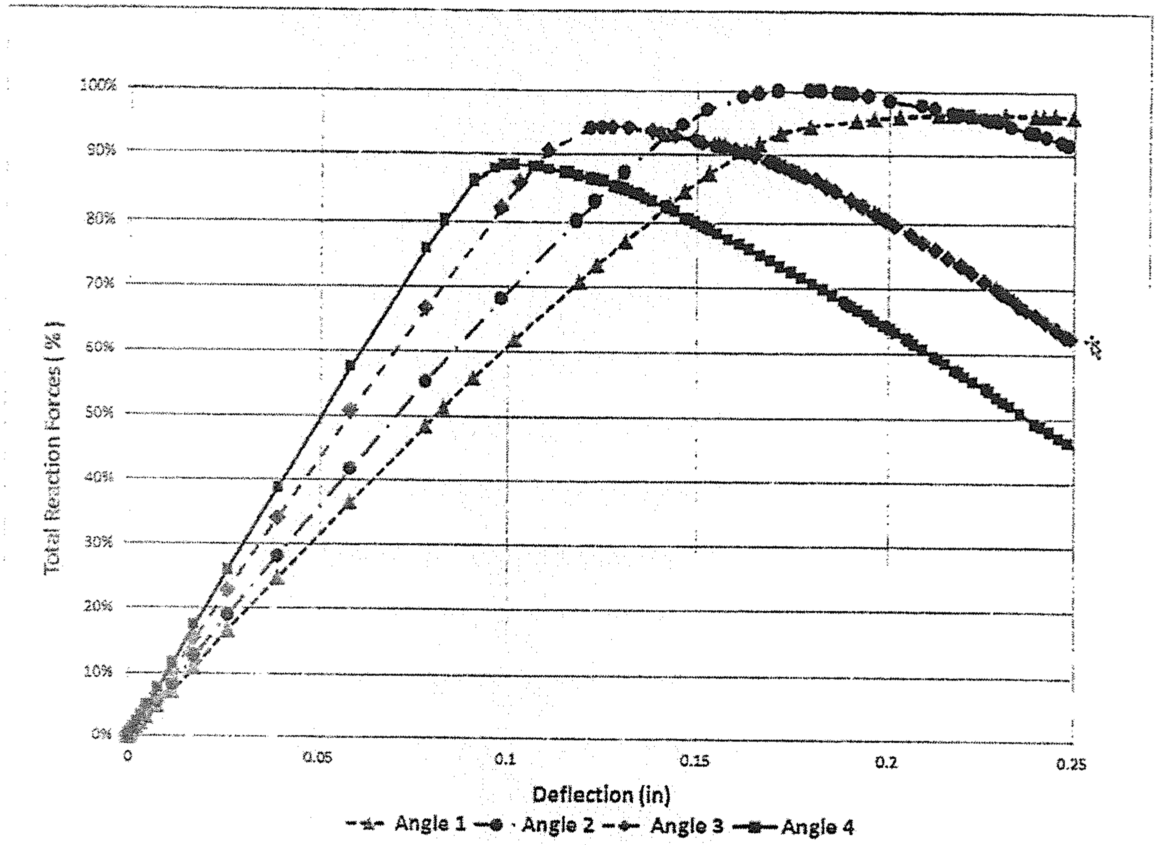


Figure 6- Effect of angle on reaction forces

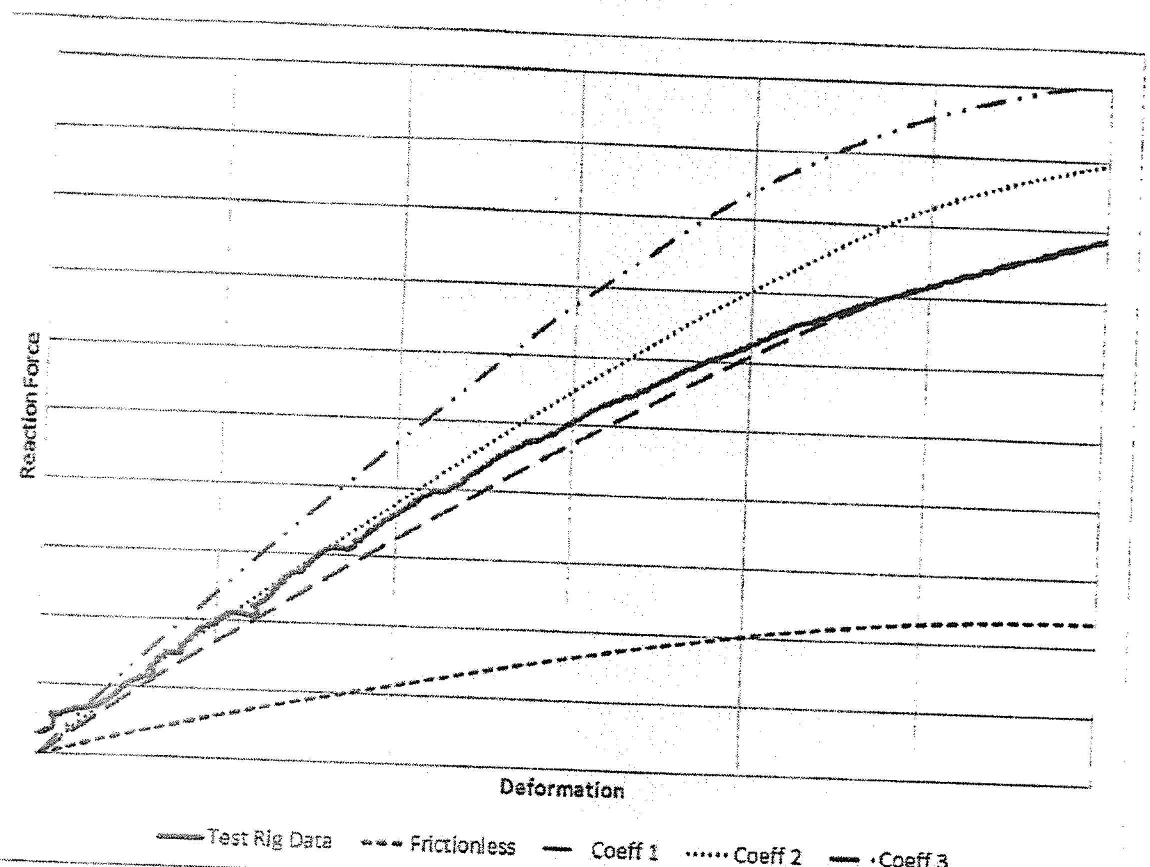
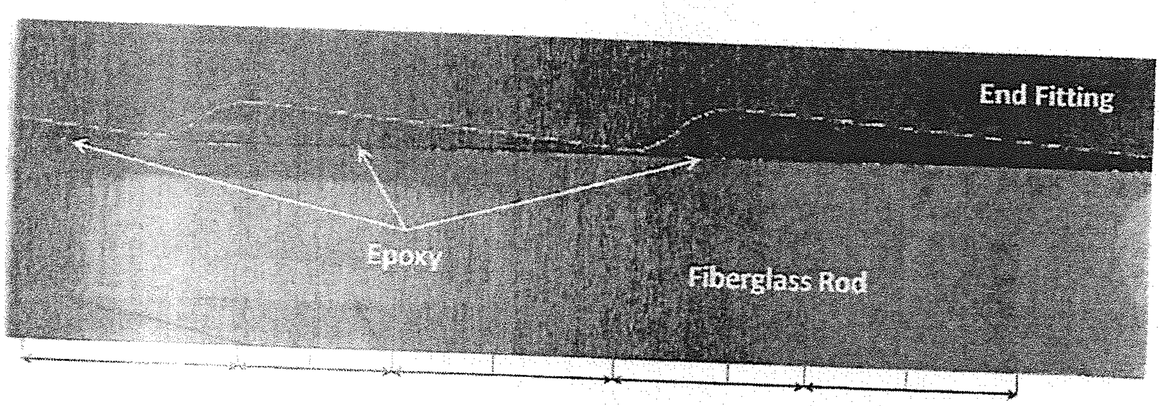


Figure 7- Correlation of FEA friction coefficient with lab data



Gradual Distribution of Stress
Figure 8- Final design with gradual distribution of stress

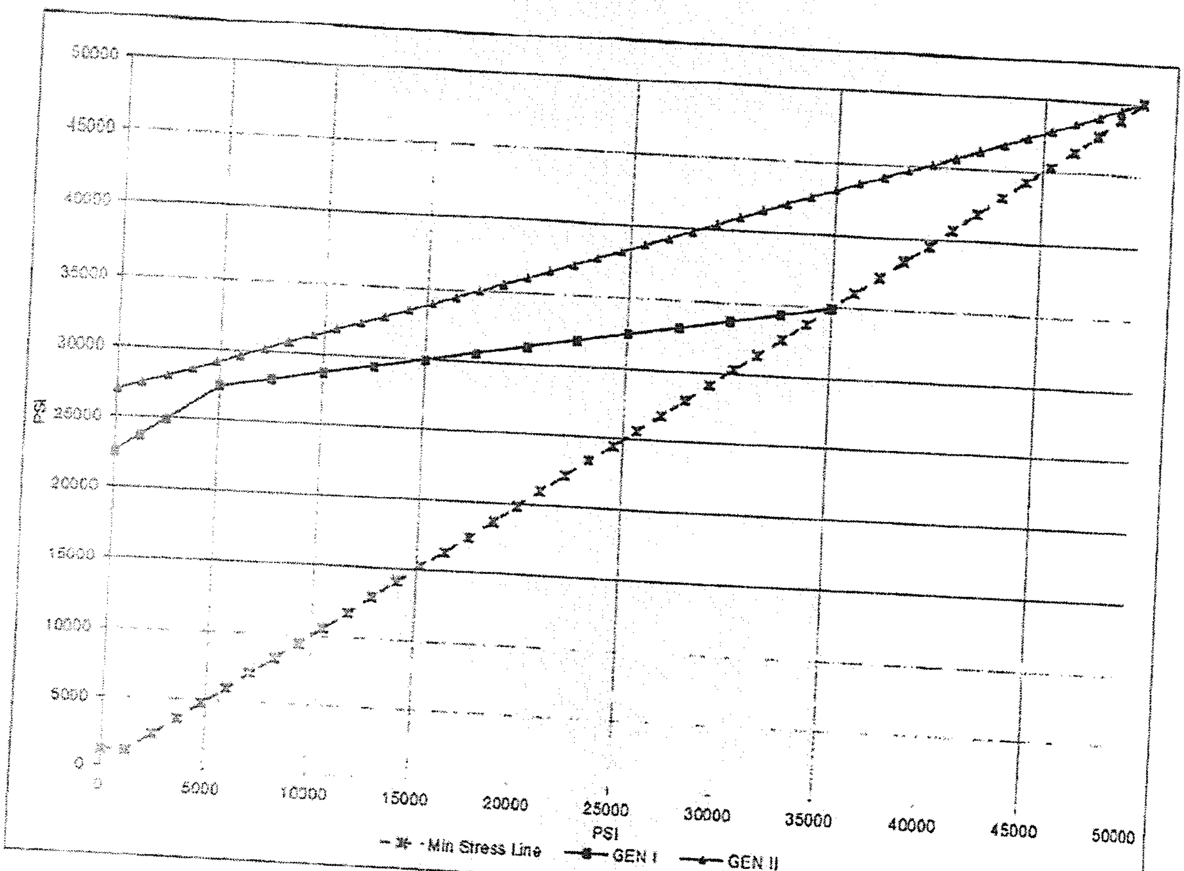


Figure 9- Stress range diagram